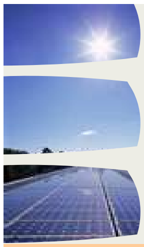


REV 2 | 2009

Solar Electric

Terms & Definitions

Array: A group of panels that comprises the complete DC PV generating unit.

Azimuth Angle: the angle clockwise from true north of the direction that the PV array faces. Due south = 180°.

BOS: Balance of System—typically denoting all components other than the PV modules, inverters and batteries.

Cell: The basic photovoltaic (PV) device that is the building block of PV modules

Concentrators: Parabolic solar collectors that concentrate the solar energy effect thereby increasing the conversion efficiency. Including “tracking” devices to follow the sun’s movement through the day.

Conversion Efficiency: The ratio of output power to input power (e.g. inverter)

Encapulstation: The method in which PV cells are protected from the environment, typically laminated between a glass superstrate and EVA substrate.

Inverter: Converts DC power from PV system to AC power for on-site use or net metering.

I_p or I_{mp}: Current at peak performance point of panel (see curve in next column).

I_{sc}: Short circuit current point of panel. Point of intersection with the Y-axis on the IV curve. (see curve in next column).

Insolation: Radiant solar energy reaching an area (kWh/(m^2-day))

Irradiance: Radiant power per unit area from the sun (Watts/m^2)

kW: kilowatt. Unit of turbine capacity.

kWh: kilowatt-hour. Unit of energy.

Magnetic Declination: Difference in degrees from magnetic north and true north. Adjustment needed to estimated energy generation of PV arrays.

MW: megawatt. Unit of turbine capacity.

MWh: Megawatt-hour. Unit of energy.

Module: A group of PV cells connected in series and/or parallel, encapsulated in an environmentally protective laminate.

Module Junction Box: An enclosed terminal block on the back of PV modules which allows the module to be connected in the electrical system.

MPPT: Maximum Power Point Tracking device (e.g. MPPT charge controller). These devices help a PV system stay at the peak power point for battery systems. Array voltage must be higher than battery voltage.

Orientation: Position of PV array with respect to true south. Differs by state/location.

Panel: A group of modules that is the building block of a PV array.

Terms & Definitions (cont.)

Panel Temperature Coefficient: Voltage change % adjustment specified by manufacturer based upon difference between STC and site annual average temperature.

Power Parrallel Connected: A method of connection in which positive terminals are connected together and negative terminals are connected together. Current output adds and voltage remains the same.

Peak Irradiance: Standard peak sunlight condition (1000 W/m^2)

Parrallel Connected: A method of connection in which positive terminals are connected together and negative terminals are connected together. Current output adds and voltage remains the same.

Peak Irradiance: Standard peak sunlight condition (1000 W/m^2)

Peak Sun Hours: 9am – 3pm

PV Panel Peak Power: Optimum performance point of panel (see curve in next column).

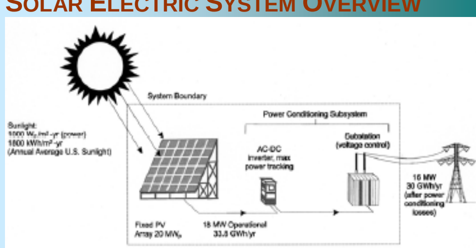
Standard Test Conditions (STC): the standard reference environment for PV cell operation is an environment of 1000 W/m^2 irradiance, 1.5 air mass, and cell temperature of 20°C.

Tilt Angle: The tilt angle is the angle from horizontal of the inclination of the PV array (0° = horizontal, 90° = vertical).

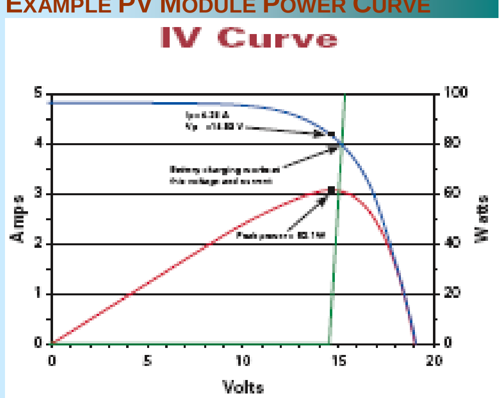
V_{oc}: Open current voltage point of panel. Point of intersection with the X-axis on the IV curve (see curve below).

V_p or V_{mp}: Voltage at peak performance point of panel (see curve below).

Solar Electric System Overview

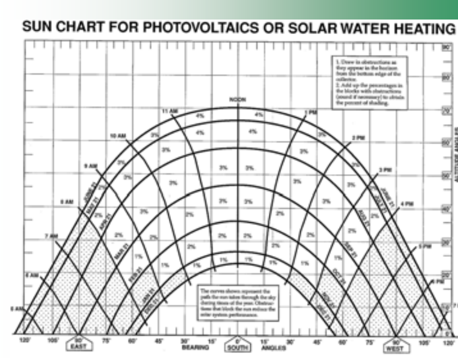


Example PV Module Power Curve



Annual Sun Position

SunChart



References/Tools

PV Watts
Performance calculator for grid-connected PV systems.
http://rredc.nrel.gov/solar/codes_algs/PVWATTS/version1/

Magnetic Declination
http://www.ngdc.noaa.gov/geomagmodels/Declination.jsp

Inverter Efficiencies
http://www.gosolarcalifornia.ca.gov/equipment/inverter.php for specific model/manufacturer inverter efficiencies.

Solar Radiation
Solar radiation data for PV flat and concentrating collectors compiled by NREL, organized by state.
http://rredc.nrel.gov/solar/pubs/redbook/

CertifiedSolar Panels
Refer to the Florida Solar Energy Center’s website for a list of certified panels
http://www.fsec.ucf.edu/en/industry/testing/PVmodules/pv_flashtest_list.htm

Wire Sizing
Minimum wire sizing calculator
http://www.elec-toolbox.com/calculators/voltdrop.htm

Energy Production Variables

Solar Resource—Usable solar radiation = average value from solar insulation table X 96%. Approximately 4% of annual solar energy is not captured due to low irradiance conditions. (ex: 100 Watt DC panel X 0.96 = 96 Watt DC net)

Soiling—Three basic categories:
1. Washed as often as necessary = 100% efficiency
2. Washed once per year = 96% efficiency (4% loss)
3. Never washed = 93% efficiency (7% loss)

Temperature (efficiency)—Estimate off of IV graph for constant voltage and variable temperature.

Module Rating—Manufacturers typically have ≤ ± 10% performance tolerance**.** Don't approve panels with a tolerance range > 10%. (ex: 88.0 + 5% watt DC module = 0.89 X 0.95 = 0.85 watts DC net)

Concentrators: Conversion efficiencies (33-40%) significantly higher than silicon solar panels at (15-20%). Check manufacturer performance data to adjust energy calculations.

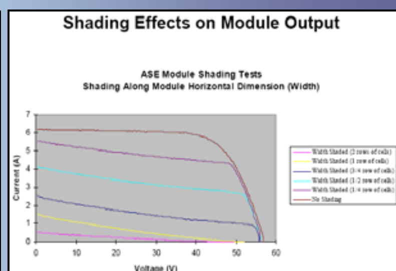
Wiring Losses & Module Mismatch: Roughly 3-5% loss in system performance.

Battery-Based Systems: 10% loss due to need for small trickle charge to maintain float voltage. DO NOT MIX BATTERY TYPES.

Inverter Efficiency: Approximately 85% for battery-based systems; 90% for batteryless systems.

Orientation Factor: Combined affects of PV array's tilt & orientation PV system performance for fixed or tracking arrays.

Shading: Use of a suncharting tool is critical to estimating shading impacts to system performance. Both manual and software versions are available for use. See Reference section for suncharting tool links.



Example of System Derating:

Derate Factors for AC Power Rating at STC		
Component Derate Factors	**PVWATTS Default**	**Range**
PV module nameplate DC rating	0.95	0.80 - 1.05
Inverter and Transformer	0.92	0.88 - 0.96
Mismatch	0.98	0.97 - 0.995
Diodes and connections	0.995	0.99 - 0.997
DC wiring	0.98	0.97 - 0.99
AC wiring	0.99	0.98 - 0.993
Soiling	0.95	0.30 - 0.995
System availabilty	0.98	0.00 - 0.995
Shading	1.00	0.00 - 1.00
Sun-tracking	1.00	0.95 - 1.00
Age	1.00	0.70 - 1.00
Overall DC-to-AC derate factor	**0.77**	

The overall DC to AC derate factor is calculated by multiplying the component derate factors. For the PVWATTS default values:

Overall DC to AC derate factor = 0.95 x 0.92 x 0.98 x 0.995 x 0.98 x 0.99 x 0.95 x 0.98 x 1.00 x 1.00 x 1.00 = 0.77 = 77%

Performance Calculation: Annual Energy = 5.7 kWh/m2/day (annual average) X 365 days/yr X 0.77

= 1602 kWh/yr/m^2

Rules of Thumb

Checking System Power—Do analysis for each string of panels separately, using worst case shading, to have the most accurate output analysis.

Roof Structural Loading—Dead loads for the addition of PV array = 3-8 psf

Materials Selection:
- Don't use dissimilar materials
- Use only sunlight resistant materials
- Structural materials:
  - Corrosion resistant aluminum 6061 or 6063
  - Hot dip galvanized steel per ASTM A123
  - Stainless steel

Waterproofing—Require builder/roofer signoff on mounting for roof mounted systems to prevent leaking at connection points.

Common PV System Electrical Design Problems:
- Insufficient conductor ampacity and insulation
- Excessive voltage drop
- Unsafe wiring methods
- Lack of or improper placement of overcurrent protection and disconnect devices.
- Use of unlisted, or improper application of listed equipment (e.g. ac in dc use).
- Lack of or improper equipment or system grounding.
- Unsafe installation and use of batteries.

Voltage Guidelines

12V—up to 100 W array, 1-2 panels in parallel.

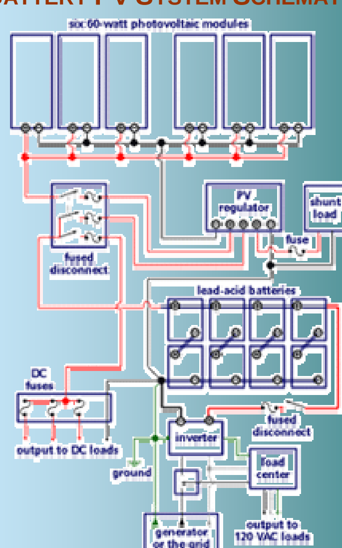
24V—100W to 300W array, parallel strings of two modules in series.

48V—Greater than 200W, parallel strings of four modules in series.

Applicable Electrical Codes

NEC—Article 690
IEEE—Standard 929
UL—1741

Simplified Battery PV System Schematic



Other

Critical Factors

Verification of shading and energy calculations.

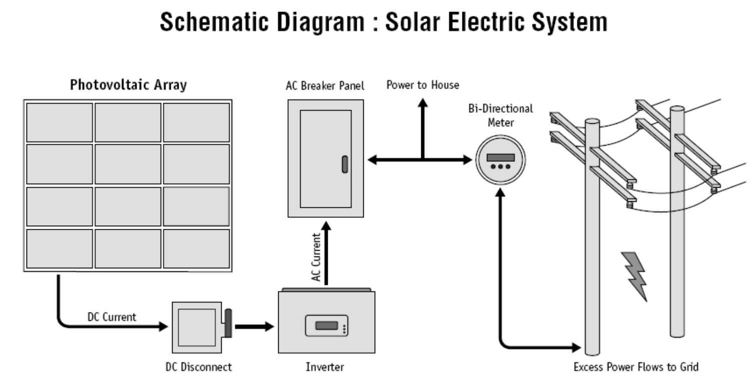
Environmental Issues

No adverse environmental issues.

Market Status

Commercially available panels and BOS. New panels and BOS continually in development to improve energy conversion efficiencies

System Design Review Calculations



Example String-Sizing Calculations

Location & Climate

Location: Corvallis, OR
Record low: -22°C (-7°F)
Average low: 1°C (34°F)
Average high: 28°C (82°F)
Record high: 42°C (108°F)

Photovoltaics

Module: SolarWorld 175 W
Voc: 44.4 V
Vmp: 35.8 V
Temperature coefficient: -0.33%/°C
Mount type: Parallel-to-roof mount
(4 in. from roof surface to back of module)

Equipment

Inverter: PV Powered 5200
Maximum Voc: 500 VDC
Minimum Vmp: 240 VDC

Calculations

Step 1. Calculate the adjusted voltage for low temperatures.

Vadj = 44.4 V x (1 + [(-22°C – 25°C) x -0.33%/°C])
Vadj = 51.3 V

Determine the maximum number of these modules in series for this inverter at this location:

Maximum number per string:
Component's max. Voc ÷ Vadj for low temperatures

500 VDC ÷ 51.3 V = 9.7 modules

Round down to the next whole number—in this case, nine modules is the maximum number in series.

Step 2. Calculate the adjusted voltage for high temperatures.

Vadj = 35.8 V x (1 + [(28°C + 35°C – 25°C) x -0.33%/°C])

(Note the additional temperature—35°C—due to the racking method.)

Vadj = 31.3 V

Determine the minimum number of these modules in series for this inverter at this location:

Minimum number per string:
Component's min. Vmp ÷ Vadj for high temperatures

240 VDC ÷ 31.3 V = 7.7

Round up to the next whole number—in this case, eight modules is the minimum number in series.

Comparing these calculations to those for other equipment will determine if you may be better off with a different combination of equipment. The minimum value calculated should always be carefully considered and is rarely the best choice. In this example, if strings of eight modules are used, the resulting Vmp on an average day will only be 250.4—precariously close to the low value (240 VDC) of the sample inverter's operating window.

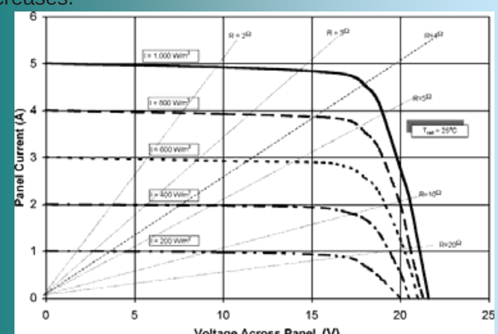
Engineering Review

Review Steps

- Check commercial availability of key system components (vendor specification sheets must be supplied)
- Verify total system generation capacity (Watts)
- Confirm solar radiation value based upon location, tilt & orientation (kWh/m^2/day). Use NREL data.
- Check shading correction factor
- Confirm array/inverter sizing check the inverter manufacturer website to for a calculator tool that determines minimum, maximum & ideal no. of panels per series string for their equipment.
- Verify the system design contains all key components and that they are adequately sized for the generation capacity (PV array, conductors (w/ sizing), overcurrent protection, charge controllers, disconnects, batteries, inverters, grounding, safety signage)
- Verify energy production calculations and derating factors. Include adjustments for panel voltage based upon average temperature difference from STD.
- Review system installation and mounting methods.
- Confirm adequacy of O&M and decommissioning procedures.
- Confirm system installed cost ($/kW) is within a reasonable range.
- Calculate simple payback using stated utility rate, system costs minus any stated incentives/tax rebates, and calculated energy production.

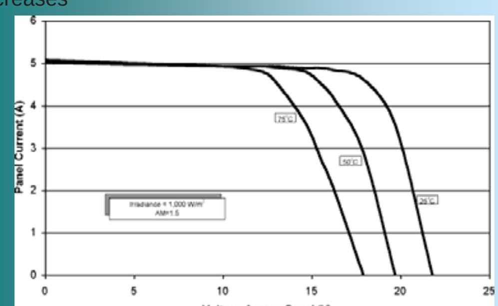
Current

Current varies with irradiance. As irradiance decreases current decreases.



Voltage

Voltage varies with temperature. As temperature increases voltage decreases



Costs/Financials

CostBreakdown (rough ratios)

Installation = 30% of cost
= 50% of cost
BOS = 15% of cost
Engineering= 5% of cost
O&M = $0.02/kWh/yr

System Cost Range

Flat Plate collector systems-- Panels $6-12/Watt

Life Cycle

20-30 years

Simple Payback

$$\frac{\text{(Total Installed System cost)} + \text{(Annual O\&M X Equip Life)}}{\text{(Annual System kWh generation) X (Utility Rate \$/kWh)}}$$